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(54) **Plasma reactor**

Plasmareaktor

Réacteur à plasma

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Description

This invention relates to plasma reactors for fabricating integrated circuits and other electronic devices on substrates, and more particularly to a plasma etch reactor providing improved processing uniformity.

Magnetic field-enhanced RIE plasma etching systems are known. In an attempt to improve the efficiency of plasma generation and etch uniformity, RIE etching has been combined with a magnetic field. Electrons generated in the RIE source have longer mean field paths in the presence of a magnetic field, resulting in more collisions with neutral species in the reactant etch gases and the generation of more ions. This improved generation of ions does not require more RF power however.

A typical prior art system is shown in Figure 1. The reactive ion etching (RIE) mode etch reactor 40 comprises a cylindrical vacuum chamber 41 containing a cathode assembly 42 which acts as a mount for the substrate to be etched. A power supply system 46, such as a 13.6 MHz RF power supply and a load matching network, is connected to the cathode. The walls 47 of the chamber act as the anode. Reactant gas is fed to the chamber via an inlet port 48 from a gas supply system 49 to a showerhead 51 within the chamber 41. Spent gases and by-products are removed via an exhaust system 50.

Electromagnets 54 and 56 are circumferentially positioned about the chamber 41 near the top and bottom thereof. The electromagnets form north and south poles which are reversible by reversing the coil current.

These systems provide a relatively high etch rate even with the use of relatively low pressures within the etch chamber. Thus they can provide high throughput of substrates to be processed without sacrificing the selectivity and directionality of the ions from the plasma with respect to the substrate to be etched. Further, since the substrate to be etched constitutes only a small part of the surface area within the etch chamber, magnetic fields parallel to the walls of the chamber can inhibit electron loss on the walls. Thus the plasma density will be maintained even though the total pressure is quite low. This process further improves the uniformity of the plasma.

However, the low pressure inside the chamber does lead to certain non-uniformities in the plasma, and this in turn leads to non-uniform etching. These non-uniformities become more important as the features sizes of semiconductor devices become smaller and the size of the wafers becomes larger.

Improvements in the above equipment have been suggested by Mantei in US Patent 4,483,737. This reference discloses a line multicusp arrangement of parallel lines of permanent magnets placed around the exterior of the process chamber arranged in straight line segments with alternating north and south poles facing inwardly toward the center of the chamber, the magnets thus being parallel to the plasma flow direction. The magnetic field generated by the axial line cusp arrangement is perpendicular to the plasma flow direction. The resultant interior magnetic field cusps about the walls confine the plasma and reduce losses of electrons to the walls of the chamber. This reduces the amount of power required to obtain the desired plasma density, while the uniformity of the plasma is increased.

However, the resultant etch apparatus has several disadvantages; because of the placement of the external magnets, the substrates cannot be admitted to and removed from the etch chamber from a position parallel to the etch position without disrupting the line of magnets, which would lead to non-uniformities in the plasma. Thus the substrate is generally admitted to the chamber below the line of magnets onto the cathode, which must be raised to an etch position within the chamber and lowered again after processing. This requires complex equipment and requires time, reducing the throughput of the equipment.

Further, it is preferred that there be no magnetic field at all in the vicinity of the substrate surface during etch processing.

WO 90/10547 discloses a plasma source having electron cyclotron resonant (ECR) heating to produce plasma for applications including chemical vapor deposition and etching. A magnetic field is formed by magnets circumferentially arranged about a cylindrical and symmetrical chamber with micro-wave power injected perpendicularly to a longitudinal axis of the chamber for preventing line-of-sight communication of resulting energised electrons through an outlet at one axial end of the chamber. The circumferential magnets are intended to cause processing of the electrons resulting in increased plasma density and ion flux or current density even at low pressures. A magnetic field free region is formed between the plasma forming region and the circumferential magnets in order to produce uniformity of plasma distribution in a plasma stream approaching the outlet.

US-A-5032202 discloses the plasma generating apparatus for plasma processing applications based on a permanement magnet line-cusp plasma confinement chamber coupled to a compact single-coil microwave wave guide launcher. The device creates an ECR plasma in the launcher and a second ECR plasma is created in the line-cusps due to a magnetic field in that region. Additional special magnetic field configuring reduces the magnetic field at the substrate to below 0.001 tesla.

An object of the present invention is to provide improvements in an RIE etch chamber by reducing electron losses and non-uniformities, reducing the magnetic field in the area of the substrate.

This invention provides a plasma reactor comprising a vacuum chamber for etching a substrate, having a source of plasma, a substrate processing region, and a magnet to create a magnetic field in the chamber, wherein the magnet comprises alternating pairs of mag-

net rings fastened to the external wall of said chamber in a direction parallel to the plane of the substrate and parallel to each other, alternating magnet rings being magnetically polarized in a direction opposite to each other to generate a ring form multi-cusp magnetic field adjacent to an inner wall of said chamber and about a substrate processing region, and wherein the chamber is provided with a slot-type substrate entry port disposed between magnet rings.

In a preferred arrangement according to the invention the chamber additionally includes a pair of permanent ring magnets about the top of the chamber adjacent to a source of plasma that reduces the magnetic field in the processing region of the chamber.

More specifically said permanent ring magnets produce a maximum field strength of about 20 Gauss or less in the substrate processing region.

In any of the above arrangements said plasma source may be an ECR source that produces a magnetic field in said plasma.

The following is a description of some specific embodiments of the invention, reference being made to the accompanying drawings, in which:

Figure 1 is a perspective view of a magnetically enhanced prior art RIE mode plasma etch system.

Figure 2 is an external front elevational view of a reactor having a cylindrical plasma source mounted on top of a cylindrical plasma etching chamber housing a cylindrical substrate chuck shown with dashed lines.

Figure 3 is a cutaway view of the plasma etching chamber encircled by magnetic rings attached to the external wall of the chamber and illustrating a port for admitting and withdrawing the substrate to be processed therein.

Figure 4 is a vertical cross sectional view of the plasma chamber of the invention showing the spacing of various elements and the shapes of the magnetic field lines within the chamber.

Specific embodiments of the invention will be described with reference to Figures 2 to 4 of the drawings.

Figure 2 is an external front elevational view of a plasma reactor 102 of the invention. A cylindrical plasma source 100, such as an ECR source, is mounted on top of the cylindrical plasma processing chamber 102. The plasma source 100 can be an electron cyclotron resonance (ECR) plasma source having a housing 104 that encloses a chamber within which a plasma is generated. A top coil 106 and a bottom coil 108 are coupled to a source of current (not shown) to produce a magnetic field of a strength on the order of about 875 Gauss. This magnetic field results in electron paths describing circular orbits around which the generated electrons circle at a frequency of about 2.455 GHz. These choices of magnetic field strength and frequency are made so that a commercially available power source at 2.455 GHz can be used to pump energy into their circling electrons. The top coil 106 is supplied by a current of 135-180 A and the bottom coil 108 is supplied by current of 100-110 A. The typical magnetic field produced by the top coil is about 900-1000 Gauss.

A gas source 110 provides a plasma process gas, typically at a flow rate of about 70-5000 sccm. An exhaust pump 112 withdraws process gases and reaction by-products at a rate sufficient to produce a pressure with the process chamber 102 of approximately 0.66×10^{-1} to 6.6×10^{1} Pa (0.5-5 millitorr).

The plasma processing chamber 102 comprises a port 114 for the entry of the generated plasma from the plasma source, an exhaust port 116 for exhausting spent gases and reaction by-products, and a cathode mount 118 (shown in dashed lines) for the substrate to be processed.

A series of at least two pairs of multicusp permanent ring magnets 120, 122, 124 and 126 are fastened to the outside of and surround the plasma processing chamber 102 in a direction parallel to the plane of the substrate and parallel to each other, but perpendicular to the direction of plasma transport from the plasma source. This arrangement produces a ring multidipole magnetic field that confines the electrons within the etching chamber 102. Each of the magnet pairs 120 and 124 is polarized such that the North pole of each of these magnets is directed toward a cylindrical axis of the plasma reactor 102. The other pair of ring magnets 122 and 126 is each magnetically polarized so that the North pole of each of these magnets is directed away from the cylindrical axis of the plasma reactor 102. The ring magnets can comprise single magnetic rings or they can be constructed of a series of bar magnets in an array fastened together by means of a suitable ferrous band, as of steel. the bar magnets suitably can be of a size of about 1.27cm (0.5 inch) high, 2.54cm (one inch) wide and 2.54cm (one inch) long. This magnet arrangement enhances etching uniformity by creating a ring cusp magnetic field that is circularly symmetrical about the reactor centerline, resulting in a more uniform plasma. The effect of these ring magnets on the magnetic fields within the processing chamber will be further illustrated and discussed with respect to Figure 4.

There is still another advantage of this magnet arrangement. Because of the present configuration of the ring magnets, the substrate to be processed, generally a semiconductor wafer, can be passed into the chamber and onto the cathode by means of a slit-type entry port 128 in the side of the chamber 102 and between a row of magnets 124, 126. This has the advantage that the magnetic fields generated about the interior walls of the chamber do not have to be interrupted to provide an entry port, which arrangement would lead to plasma non-uniformities. Further, a simplified, stationary cathode mount can be provided within the chamber. The present system also provides convenient and easy access for robotic handling of the substrates to be processed. In addition, since the substrate to be processed can be admitted and extracted from the vacuum chamber in the same plane, the throughput is maximized for increased

efficiency.

A further important feature of the present invention is a large pair of permanent ring magnets 130 and 132 fastened to the top of the reaction chamber 102. These magnets comprise the matching section to join the strong field of the ECR source to the ring cusp field. These magnets also improve the uniformity of the plasma and etching by removing magnetic field lines exiting the plasma source, terminating them before or shortly after they enter the etching chamber. The direction of magnetization is axial with respect to the chamber central axis and thus differs from the other ring magnets 120-126. For this specific plasma source, this ring magnet should be about three times the width of the ring magnets illustrated as 120-126. Suitably these large ring magnets 130, 132, can be about 3.81cm (1.5 inches) high and 2.54cm (one inch) wide. The effect of these large ring magnets on the magnetic fields within the processing chamber 102 will also be further discussed with reference to Figure 4.

As is well known, the reaction chamber 102 can also be optionally provided with instrument ports, view ports and the like, and other equipment, if desired to monitor the reactions taking place within the chamber during processing for example.

The substrate entry port 128 is a slot type port which is less than about 2.54cm (one inch) high and is wide enough to admit the desired substrate diameter. For example, state of the art semiconductor wafers are 15.24 to 20.32cm (6 to 8 inches) in diameter. This port 128 is of standard manufacture except that some modification may be required to enable the port 128 to fit over the ring magnets 120 - 126. The advantage to a slot type port is that the substrates to be processed may be transferred into and out of the processing chamber 102 in the orientation and position within the chamber in which they will be processed. This greatly simplifies ingress and egress of the substrate and allows the cathode mount to be fixed, eliminating the need for complex mechanisms to raise and lower the substrate to the processing position. However, an adjustable substrate mount can of course be utilized if desired to optimize the position of the substrate within the substrate processing region around the substrate.

Figure 3 is a cutaway view of the chamber 102 in which the ring magnets 120 and 124 consist of a circular array of bar magnets. These bar magnets have their North poles oriented toward and normal to the cylindrical axis of the chamber 102. In the ring magnets 122 and 126, each of the bar magnets has its North pole oriented directly away from and normal to the cylindrical axis of the chamber 102.

Figure 4 is a vertical cross section of the plasma reactor 98 illustrating the spacing of various elements and the shapes of the magnetic field lines generated in the reactor. Magnetic field lines 134 and 136 within the plasma source 100 are produced primarily by the coils 106 and 108. Because of the large amplitude of the magnetic field within the plasma source 100, this field would introduce non-uniformities into the ion density within the substrate processing region 138 at the top surface of the substrate during processing. The large ring magnet 132 is positioned and oriented with its North pole oriented vertically upward parallel to the cylindrical axis of the reactor 98 so that a large portion of the magnetic field lines 134 are bent in the region 140, in effect providing a return path for such field lines. The ring magnet 130 in turn has its North pole oriented perpendicular to and away from the cylindrical axis of the reactor 102 to divert additional field lines 136 away from the substrate processing region 138 in the region 142 and to an extent sufficient to reduce the magnetic field below about 20 Gauss at the surface of the substrate. Thus the magnetic field lines emanating from the plasma source. 100 are pulled up towards the top 144 of the chamber 102. This greatly reduces the magnetic field in the vicinity of the substrate which would generate non-uniformities in the plasma near the substrate surface.

As can also be seen in Figure 4, the ring magnets of alternating magnetic orientation create a series of curved magnetic fields 146, 148 which keep the electrons in the plasma from contacting the wall 150 of the chamber 102 where they would be lost. Thus the alternating ring magnets further enhance the efficiency of the plasma. The presence of the large ring magnets 130, 132, also cooperate with the ring magnets 120-126 to produce the ring multicusp magnetic field inside the reactor sidewall 150.

The spacing between the magnet ring pairs, such as 120 and 122 and the strengths of the magnetic fields produced by these magnets are selected so that their field lines do not significantly pass through the substrate processing region. Because these field lines penetrate into the processing chamber 102 a distance comparable to the spacing between these ring magnets, this spacing is selected to be on the order of or less than the spacing between the outer edge of the wafer and the inner edge of the sidewall 150. This spacing is typically at least 5.08cm (two inches) to provide a sufficient flow path for gases to enable the exhaust pump (not shown) to produce the desired processing pressure within the reactor 98. Thus the magnet rings may be separated by approximately 5.08cm (two inches) spaces. This choice of parameters produces a substantially field free region 138 that includes within it the substrate processing region. By substantially "field free" is meant that the magnetic field within this region is less than about 20 Gauss . The dashed lines marked as 20, 50, 100 and 200 Gauss respectively in Fig. 4 confirm that the processing region 138 is substantially free of magnet fields.

Although the invention has been described with respect to particular equipment and embodiments, various substitutions can be made without deviating from the invention as claimed as will be apparent to those skilled in the art, and are to be included herein. The size of the vacuum chamber will determine the size and

spacing of the magnetic bands around the chamber, including both the larger permanent magnet band and the magnetic ring pairs. The nature of the source magnetic field will determine the size and strength of the necessary matching section which for the embodiment shown hereinabove was composed of magnet rings 130 and 132.

Claims

1. A plasma reactor comprising a vacuum chamber (102) for etching a substrate, having a source of plasma (100,110), a substrate processing region (138), and a magnet to create a magnetic field in the chamber,
   characterised in that the magnet comprises alternating pairs of magnet rings (120,122,124,126) fastened to the external wall (150) of said chamber (102) in a direction parallel to the plane of the substrate and parallel to each other, alternating magnet rings being magnetically polarized in a direction opposite to each other to generate a ring form multicusp magnetic field adjacent to an inner wall of said chamber and about said substrate processing region (138); and in that the chamber has a slot-type substrate entry port (128) located between magnet rings.

2. A plasma reactor according to claim 1, characterised in that said chamber additionally includes a pair of permanent ring magnets (130,132) about the top of the chamber adjacent to a source of plasma that reduces the magnetic field in the processing region of the chamber.

3. A reactor according to Claim 1 or Claim 2, characterised in that said permanent ring magnets produce a maximum field strength of about 20 Gauss or less in the substrate processing region.

4. A plasma reactor according to any one of Claims 1 to 3, characterised in that said plasma source is an ECR source (100) that produces a magnetic field in said plasma.

Patentansprüche

1. Plasmareaktor mit einer Vakuumkammer (102) zum Ätzen eines Substrats, welche eine Plasmaquelle (100, 110), einen Substratbehandlungsbereich (138) und einen Magneten zur Erzeugung eines Magnetfelds in der Kammer aufweist, dadurch gekennzeichnet, daß der Magnet abwechselnde Paare von Magnetringen (120, 122, 124, 126) aufweist, die an der Außenwand (150) der Kammer (102) in einer Richtung parallel zur Ebene des Substrats und parallel zueinander befestigt sind, wobei die abwechselnden Magnetringe in einer zueinander entgegengesetzten Richtung magnetisch polarisiert sind, um angrenzend an eine Innenwand der Kammer und um den Substratbehandlungsbereich (138) herum ein ringförmiges Mehrfachspitzen-Magnetfeld zu erzeugen, und daß die Kammer eine schlitzartige Substrateinlaßöffnung (128) hat, die zwischen den Magnetringen angeordnet ist.

2. Plasmareaktor nach Anspruch 1, dadurch gekennzeichnet, daß die Kammer zusätzlich um die Oberseite der Kammer herum angrenzend an eine Plasmaquelle ein Paar von Ringpermanentmagneten (130, 132) aufweist, welches das Magnetfeld in dem Behandlungsbereich der Kammer abschwächt.

3. Reaktor nach Anspruch 1 oder Anspruch 2, dadurch gekennzeichnet, daß die Ringpermanentmagneten eine maximale Feldstärke von etwa 20 Gauß oder weniger in dem Substratbehandlungsbereich erzeugen.

4. Plasmareaktor nach einem der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß die Plasmaquelle eine ECR-Quelle (100) ist, die ein Magnetfeld in dem Plasma erzeugt.

Revendications

1. Réacteur à plasma comportant une chambre à vide (102) pour l'attaque chimique d'un substrat, ayant une source de plasma (100, 110), une zone (138) de traitement de substrats et un aimant pour engendrer un champ magnétique dans la chambre,
   caractérisé en ce que l'aimant comporte des paires alternées d'anneaux magnétiques (120, 122, 124, 126) fixés à la paroi extérieure (150) de ladite chambre (102) dans une direction parallèle au plan du substrat et parallèlement entre eux, des anneaux magnétiques alternés étant polarisés magnétiquement dans des sens mutuellement opposés pour générer un champ magnétique de forme annulaire à pointes multiples adjacent à une paroi intérieure de ladite chambre et autour de ladite zone (138) de traitement de substrats ; et en ce que la chambre présente une ouverture (128) d'entrée de substrat du type fente située entre des anneaux magnétiques.

2. Réacteur à plasma selon la revendication 1,
   caractérisé en ce que ladite chambre comprend en outre une paire d'aimants permanents annulaires (130, 132) autour du sommet de la chambre, adjacents à une source de plasma, qui réduit le champ magnétique dans la zone de traitement

de la chambre.

3. Réacteur selon la revendication 1 ou la revendication 2, caractérisé en ce que lesdits aimants permanents annulaires produisent un champ d'une force maximale d'environ 20 Gauss ou moins dans la zone de traitement de substrats.

4. Réacteur à plasma selon l'une quelconque des revendications 1 à 3, caractérisé en ce que ladite source de plasma est une source ECR (100) qui produit un champ magnétique dans ledit plasma.

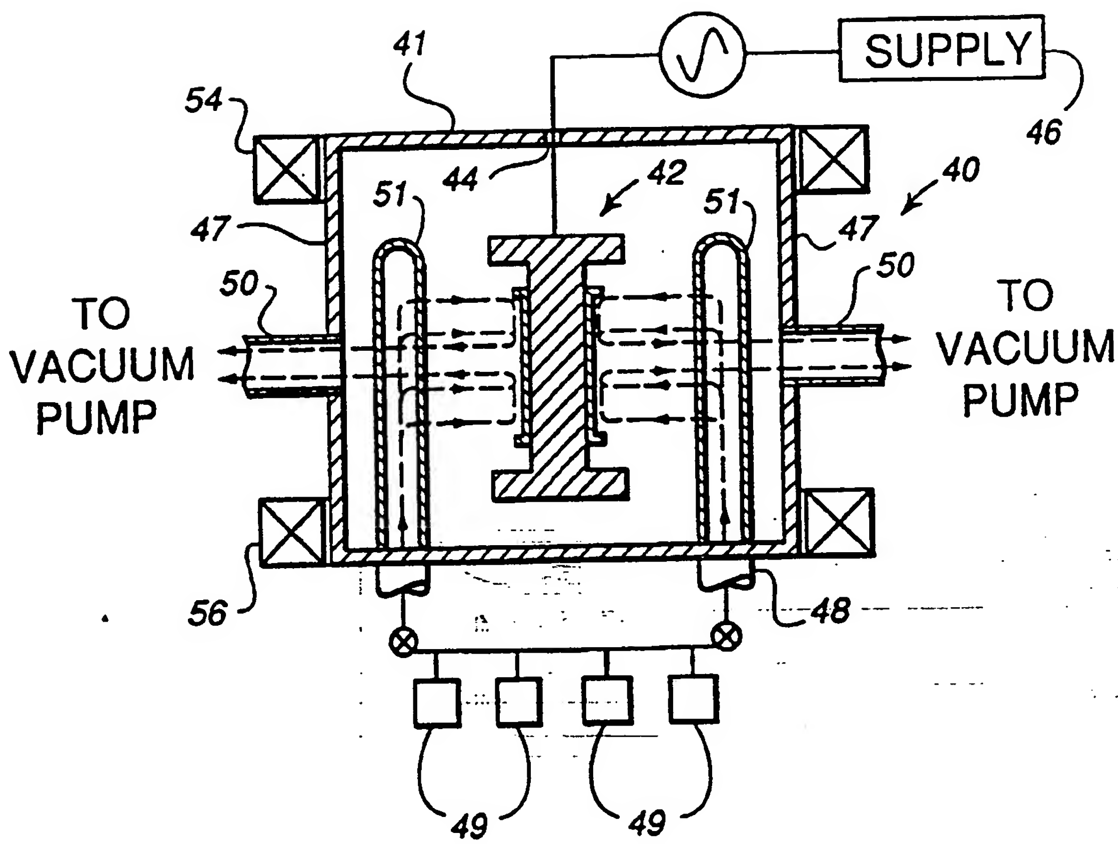
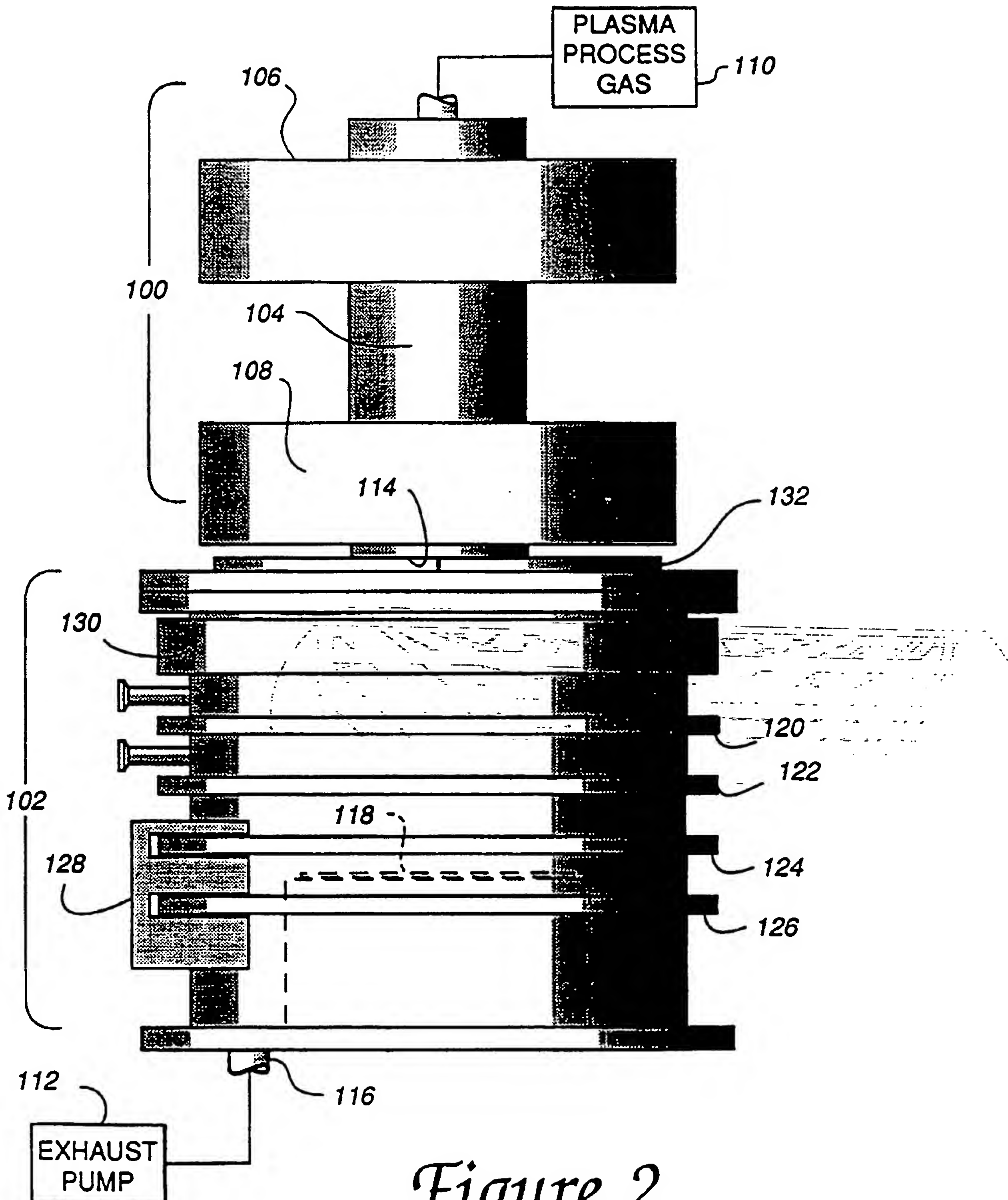


Figure 1 (PRIOR ART)


PLASMA
PROCESS
GAS
110
106
100
104
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114
132
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128
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126
112
116
EXHAUST
PUMP

Figure 2

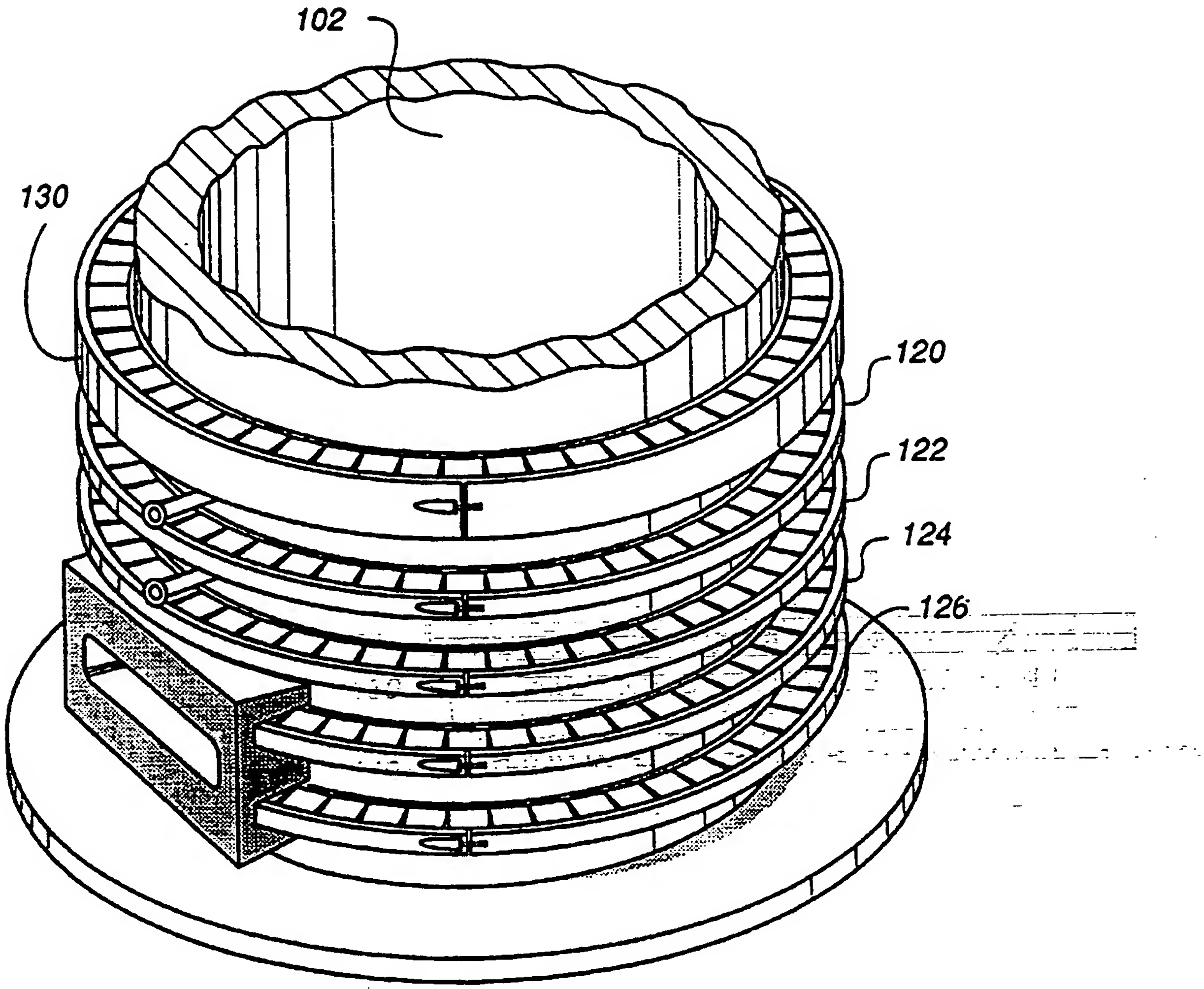
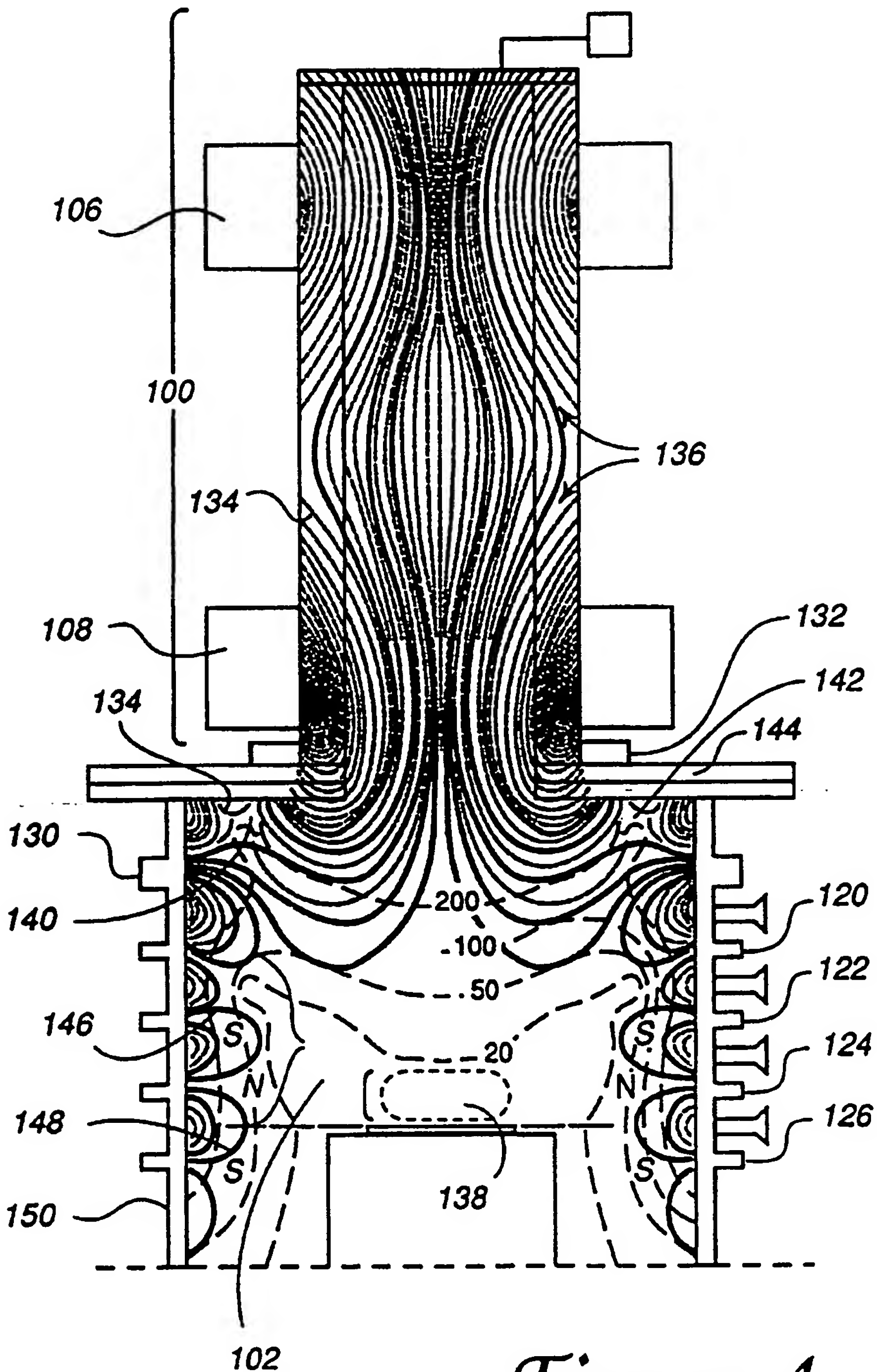


Figure 3



106
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136
108
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144
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200
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50
120
122
146
S
20
124
N
N
148
S
126
S
S
150
138
102

Figure 4